g-2 J-PARC (E34)

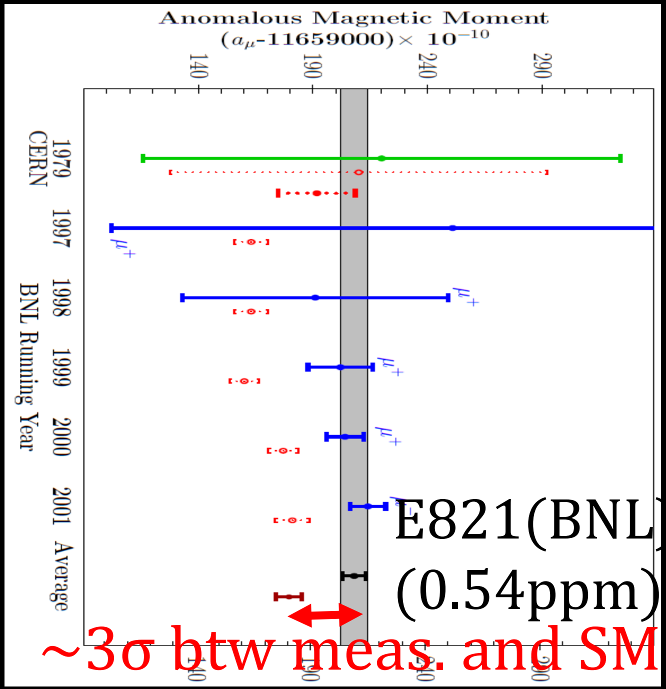
M. Otani (KEK)
for E34 collaboration

2015/8/11

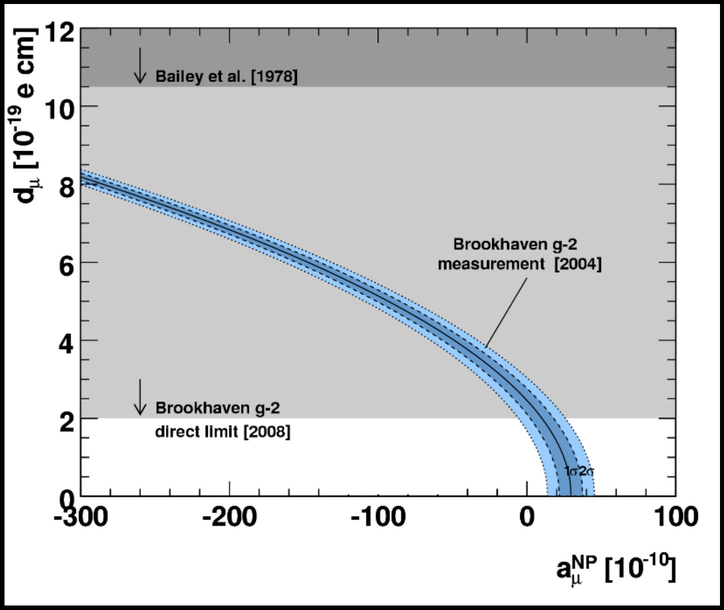
1. Introduction
2. E34 experiment
3. Status of each experimental components
4. Summary

Muon g-2 and EDM

- As already introduced, muon g-2 has a 3σ discrepancy between measurement and the SM prediction.
- Search for μEDM is also important for it.



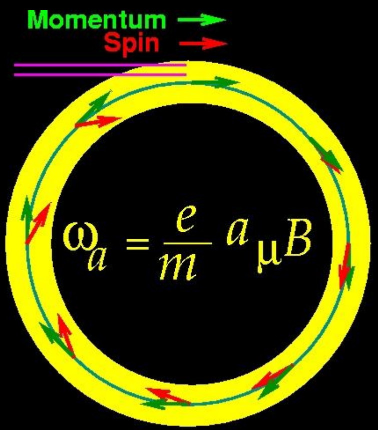
J.L. Feng et al. Nucl. Phys. B 613, 366 (2001)



$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c} + \boxed{\frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)}\right]$$

Need more precise and independent measurement

Our Approach

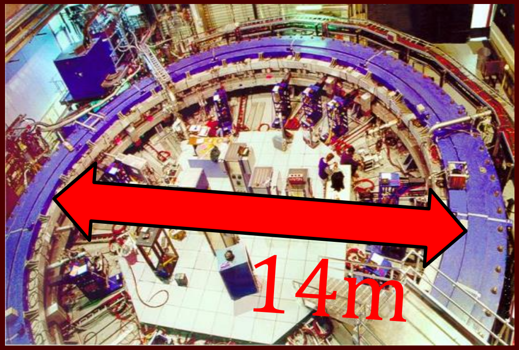


$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$

BNL E821/Fermi

Magic momentum (p=3.1 GeV/c)

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$

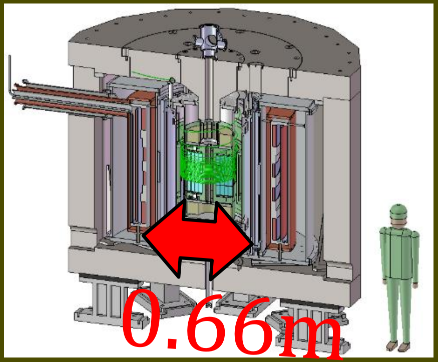


P=3.1 GeV/c
T=1.45 T

J-PARC

no electric focusing

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B}\right)\right]$$



P=0.3 GeV/c
T=3.0 T

Independent technique

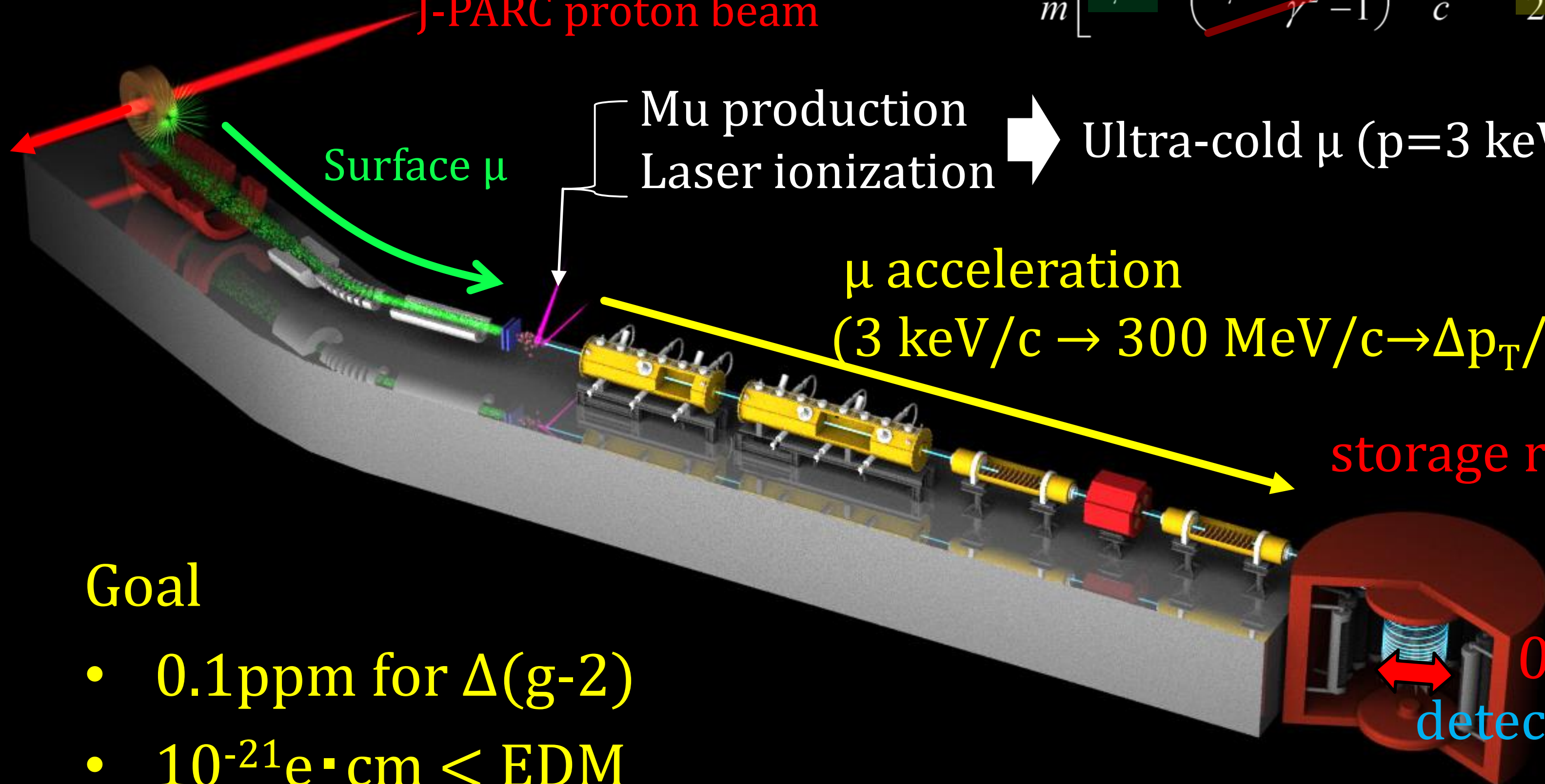
Smaller storage, complete coverage…

J-PARC E34

- High precision measurement of (g-2/EDM)$_\mu$ at J-PARC MLF with a newly developed method, ultra-cold muon beam.

w/o E focusing at storage

$$\vec{\omega} = -\frac{e}{m}\left[\boxed{a_\mu \vec{B}} - \cancel{\left(a_\mu - \frac{1}{\gamma^2 - 1} \right) \frac{\vec{\beta} \times \vec{E}}{c}} + \boxed{\frac{\eta}{2}\left(\vec{\beta} \times \vec{B}\right.} \left. + \cancel{\frac{\vec{E}}{c}} \right) \right]$$



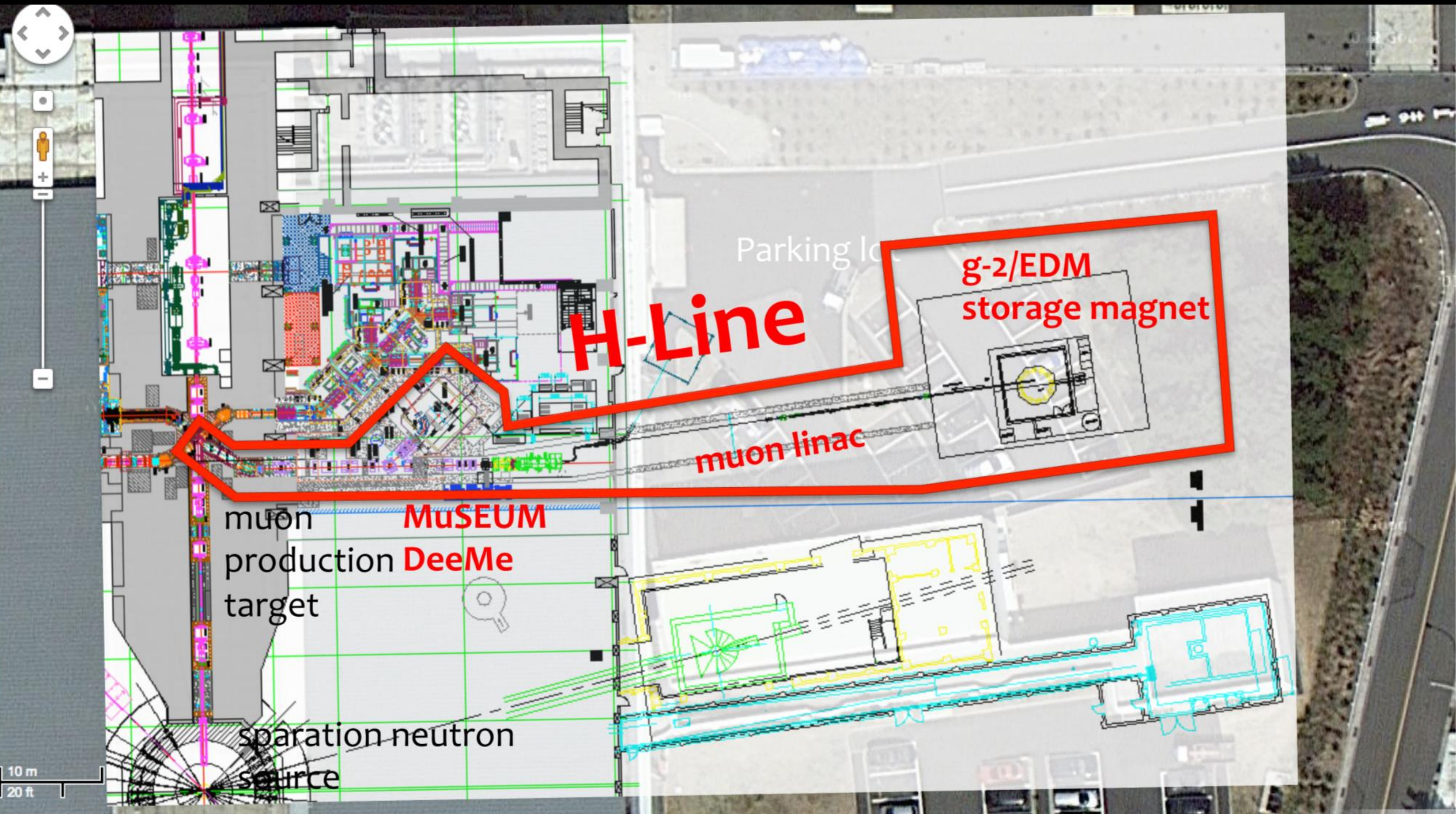
Goal

- 0.1ppm for Δ(g-2)
- 10^{-21}e･cm < EDM


J-PARC Facility
(KEK/JAEA)
LINAC
3 GeV
Synchrotron
Neutrino Beam
To Kamioka
Material and Life Science
Facility
Main Ring
(30 GeV)
Hadron Hall
Bird's eye photo in Feb. 2008

Experimental Site

MLF (Material and Life Science Facility) and extended building



E34 collaboration

June 2015,
collaboration meeting @J-PARC

Msaharu Aoki[8], Pavel Bakule[20], Bernd Bassalleck[24], George Beer[26], Gerry Bunce[27], Abhay Deshpande[19], Simon Eidelman[4], Douglas E. Fields[24], Miloslav Finger[6], Michael Finger Jr.[6], Yuya Fujiwara[17,14], Yoshinori Fukao[10], Noriyosu Hayashizaki[16], Seiko Hirota[10,14], Hiromi Iinuma[10], Masanori Ikegami[10], Masahiro Ikeno[10], Katsuhiko Ishida[17], Masa Iwasaki[17], Ryosuke Kadono[10], Takuya Kakurai[12], Takuya Kamitani[10], Yukihide Kamiya[10], Sohtaro Kanda[12], Frédéric Kapusta[5], Naritoshi Kawamura[12], Takashi Kohriki[10], Sachio Komamiya[14], Kunio Koseki[10], Yoshitaka Kuno[8], Alfredo Luccio[12], Oleg Luchev[2], Muneyoshi Maki[12], Glen Marshall[22], Mika Masuzawa[10], Yasuyuki Matsuda[9], Teijiro Matsuzaki[17], Tsutomu Mibe[10], Katsumi Midorikawa[2], Satoshi Mihara[10], Yasuhiro Miyake[10], William M. Morse[3], Jiro Murata[17,13], Ryotaro Muto[10], Kanetada Nagamine[23,10,18], Takashi Naito[10], Hisayoshi Nakayama[10], Megumi Naruki[10], Makiko Nio[21], Hajime Nishiguchi[10], Daisuke Nomura[10], Hiroyuki Noumi[15], Tomoko Ogawa[2], Toru Ogitsu[10], Kazuki. Ohishi[17], Katsunobu Oide[10], Masahiro Okamura[3], Art Olin[22,26], Norihito F. Saito[2], Naohito Saito[10,14], Yasuhiro Sakemi[7], Ken-ichi Sasaki[10], Osamu Sasaki[10], Akira Sato[12], Aurore Savoy-Navaro[5], Yannis K. Semertzidis[3], Yuri Shatunov[12], Koichiro Shimomura[10], Boris Shwartz[4], Wilfrid da Silva[25], Patrick Strasser[10], Ryuhei Sugahara[10], Michinaka Sugano[10], Ken-ichi Tanaka[10], Manobu Tanaka[10], Nobuhiro Terunuma[10], Nobukazu Toge[10], Dai Tomono[17], Eiko Torikai[12], Toshiyuki Toshito[11], Akihisa Toyoda[10], Kyo Tsukada[12], Tomohisa Uchida[10], Kazuki Ueno[17], Vlasov Vrba[1], Satoshi Wada[2], Akira Yamamoto, Kaoru Yokoya, Koji Yokoyama, Makoto Yoshida, Mitsuhiro Yoshida, Koji Yoshimura[10]

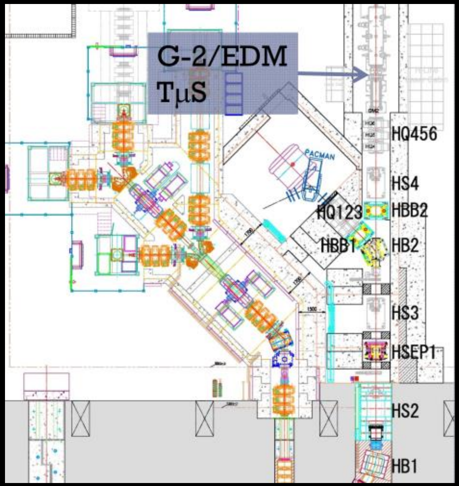
129 members from 9 countries

N. Kawamura, M. Otani and MLF Muon Section

Surface Muon Beamline

- Frontend magnets (capture and bending) were installed.

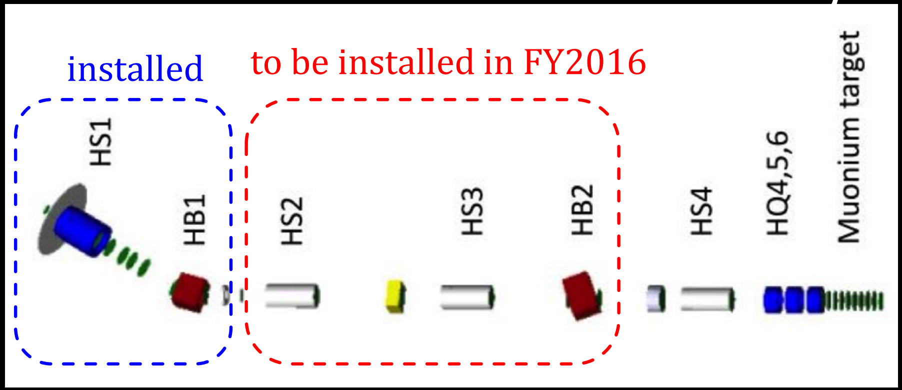
drawing

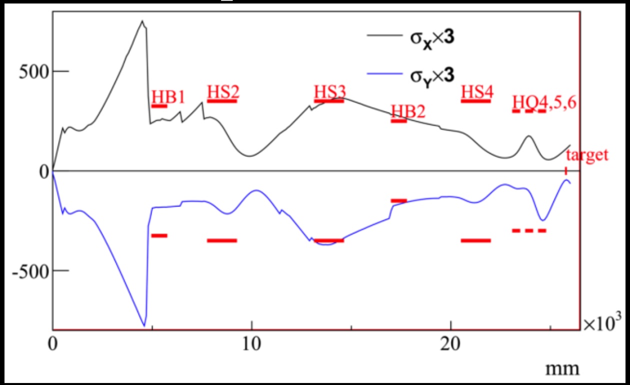


Status in 2014

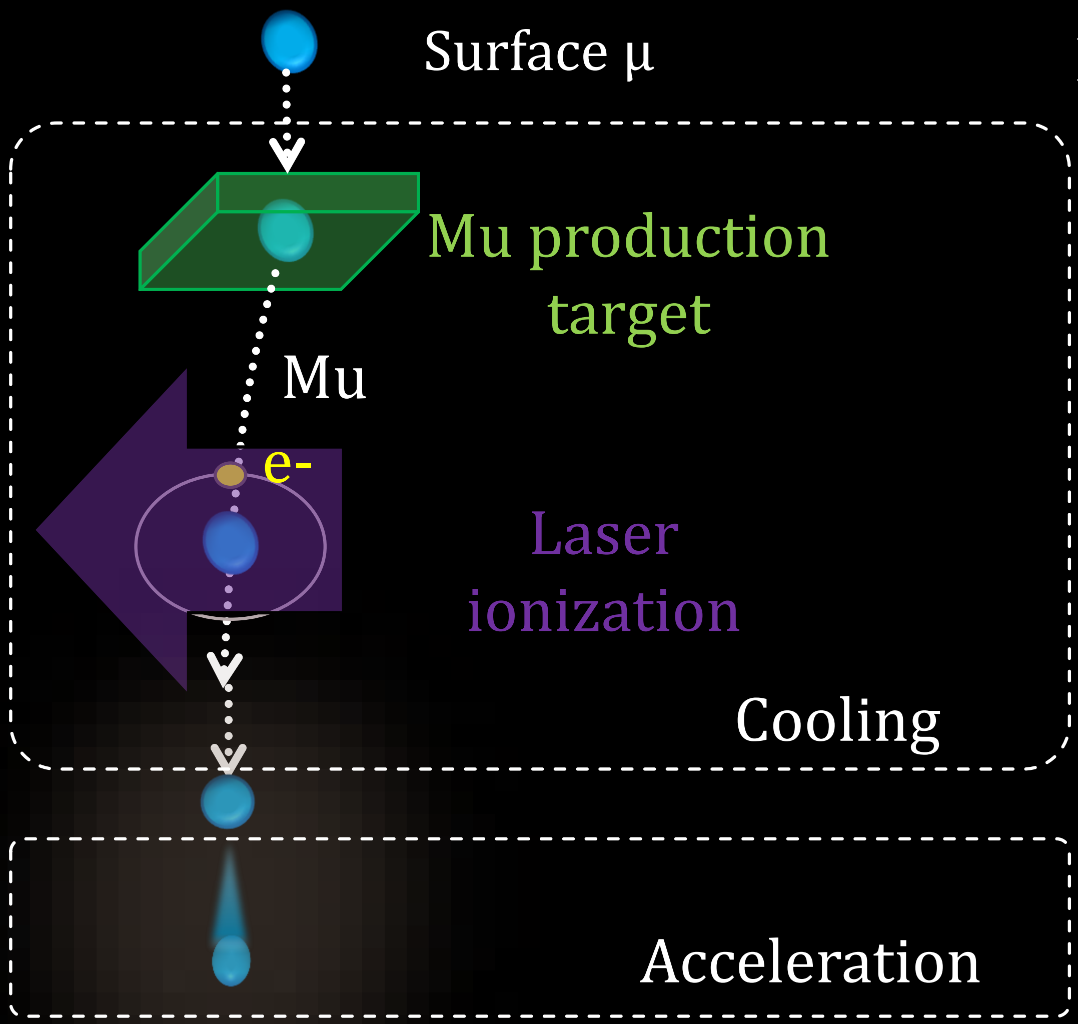
- Downstream beamline optics is designed by simulation (g4beamline). Up to H1 area will be constructed in next year.

Simulation setup and envelope





Ultra-cold Muon Beam



E=4MeV, p=28 MeV/c

30 meV, 3 keV/c

212 MeV, 0.3 GeV/c

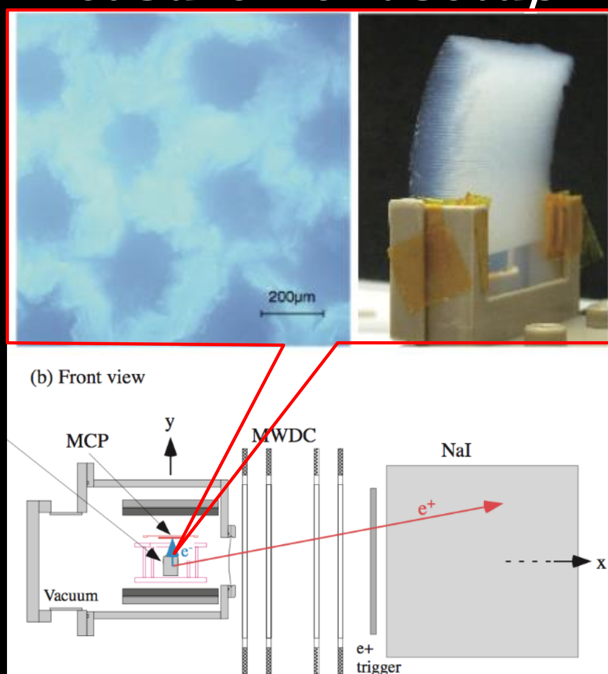
$\Delta p_T/p = 10^{-5}$

RIKEN, TRIUMF, UVic, Chiba Univ., Korea U, KEK

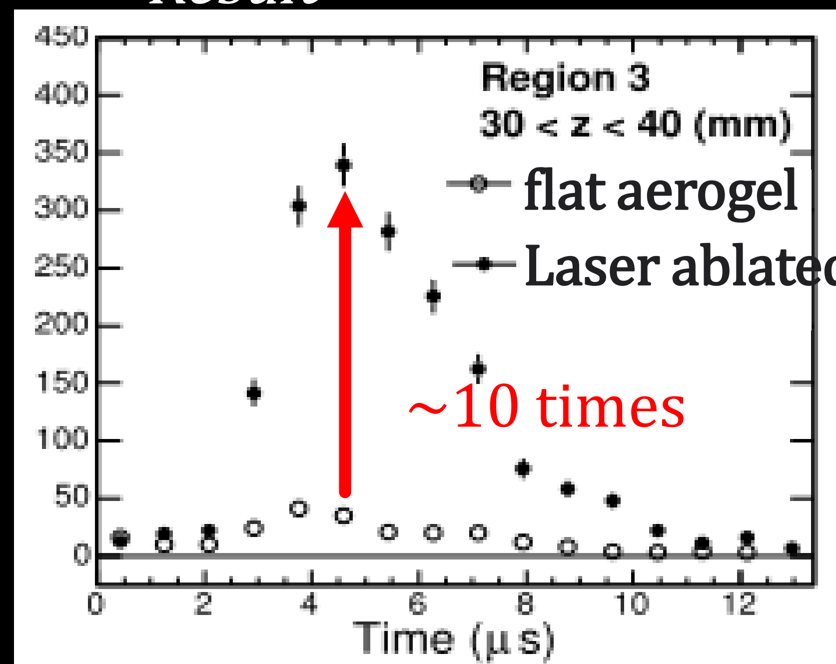
Mu Production Target

- Subsequent measurements were done at TRIUMF
  - Silica Aerogel [PTEP 2013 (2013) 103C01]
  - Laser ablated Silica Aerogel [PTEP 2014 (2014) 091C01]

Measurement setup



Result

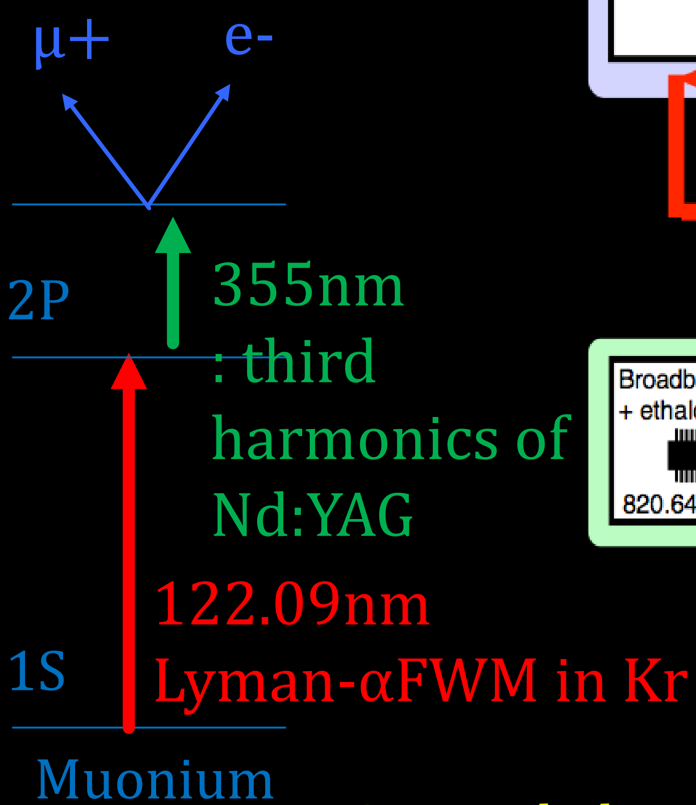


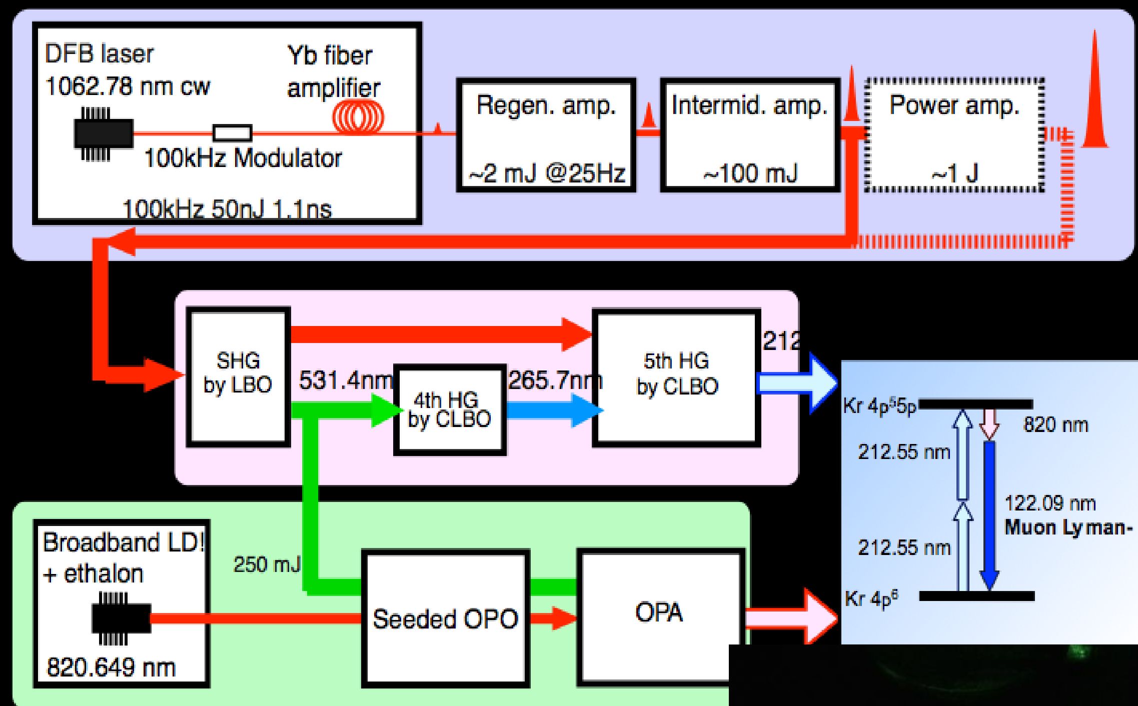
Succeeded to develop efficient target (~10 times)

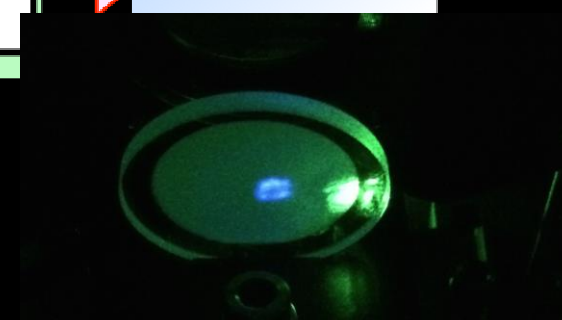
RIKEN, TRIUMF, KEK/J-PARC

Laser Ionization

- Mu is ionized by two laser lights.



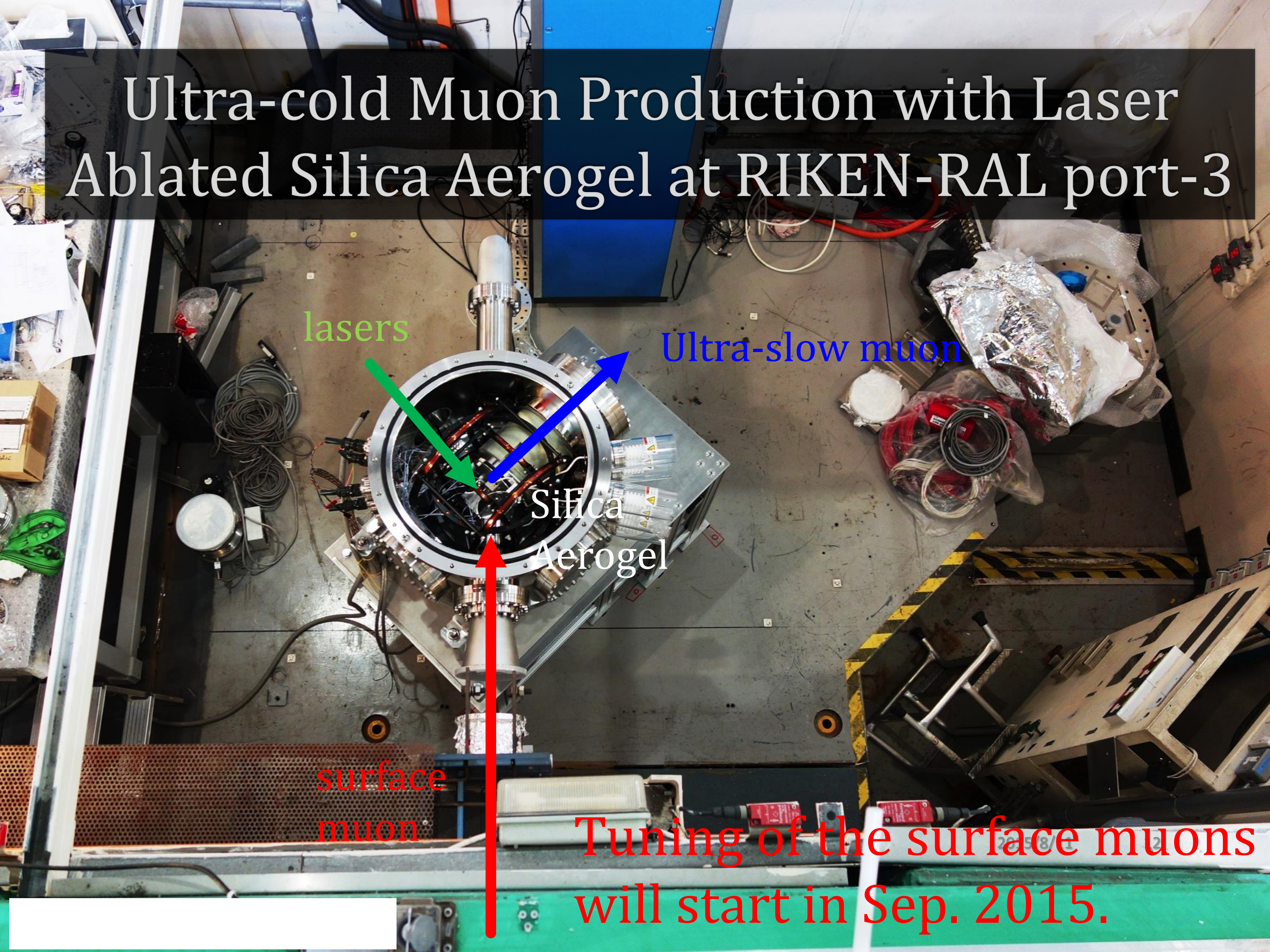




Succeeded to generate Lyman-α @J-PARC U-line in May 2014

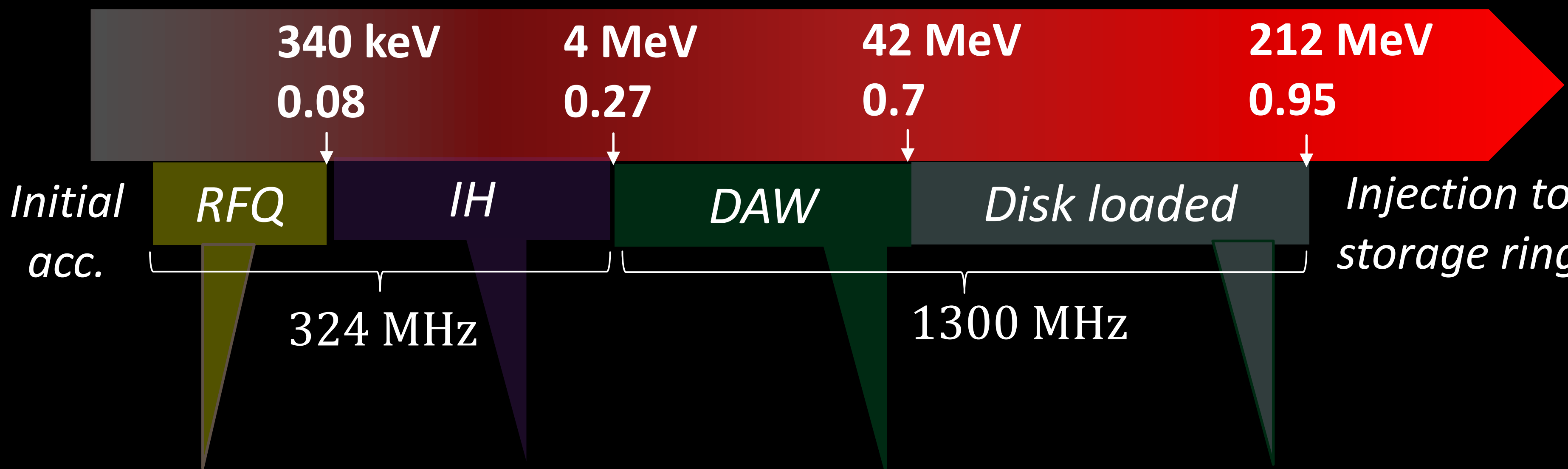
Power amp. (x10) to be installed for higher power

Ultra-cold Muon Production with Laser Ablated Silica Aerogel at RIKEN-RAL port-3

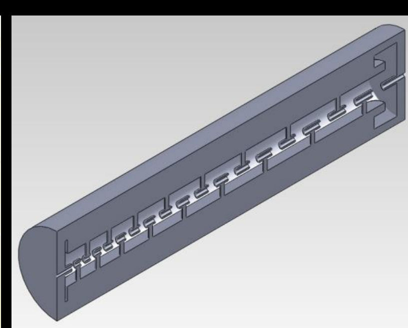


Muon Acceleration

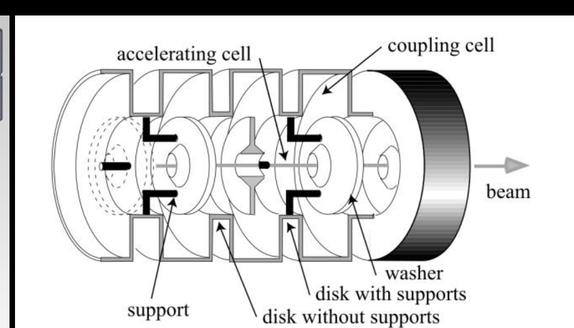
- LINAC dedicated muon is being developed.
- Several RF cavities are adopted along with β



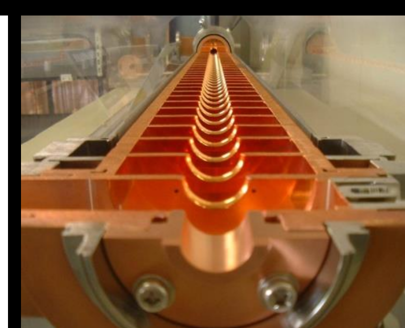
- Y. Kondo et al. Phys. Rev. ST Accel. Beam 16. 040102 (2013)
- Y. Kondo et al.: Proc. of IPAC2015, THPF045 (2015)



- K. Saito, Master Thesis, Tokyo Tech., (2012)



- HiroyukiAoetal.,Jpn.J.Appl.Phys.Vol. 39(2000)651-656
- M. Otani et al., PASJ 2014 (2014) SAP039



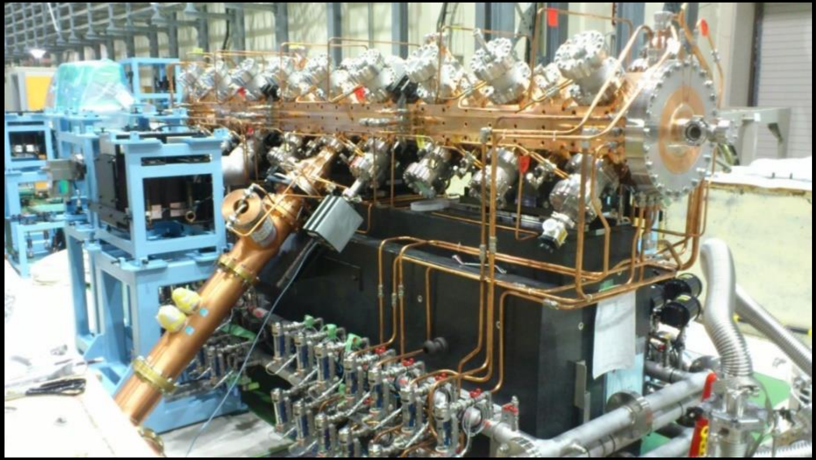
- M. Yoshida, Proceedings for IPAC 2015

Y. Kondo, S. Artikova

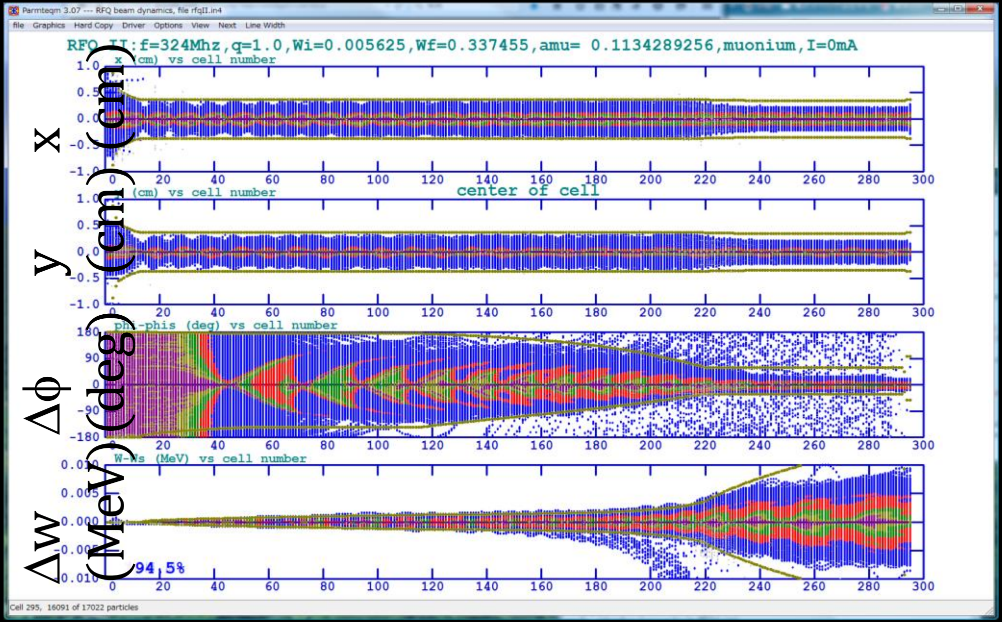
RFQ

- Bunching + acceleration (5 keV→340 keV)
- So called RFQ II, which is originally developed for J-PARC LINAC spare, can be utilized for muon

RFQ II photo@J-PARC LINAC



Simulation (PARMTEQ) result

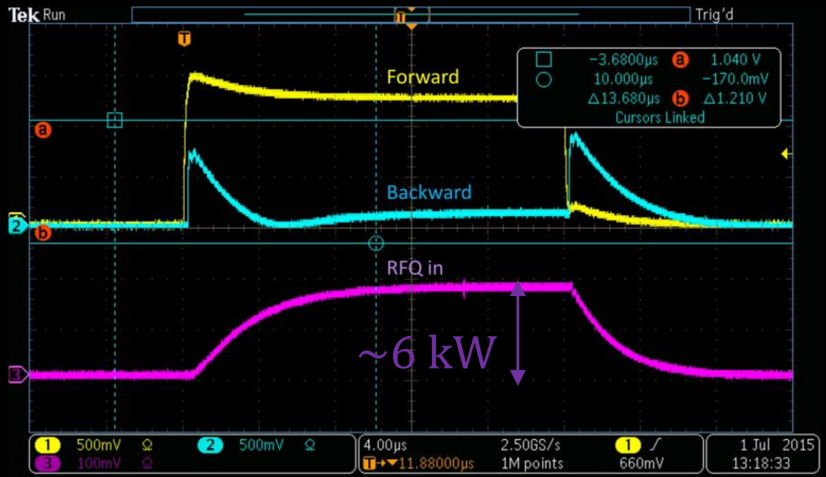


Transmission 95%, muon survival 81%, total eff. 77%

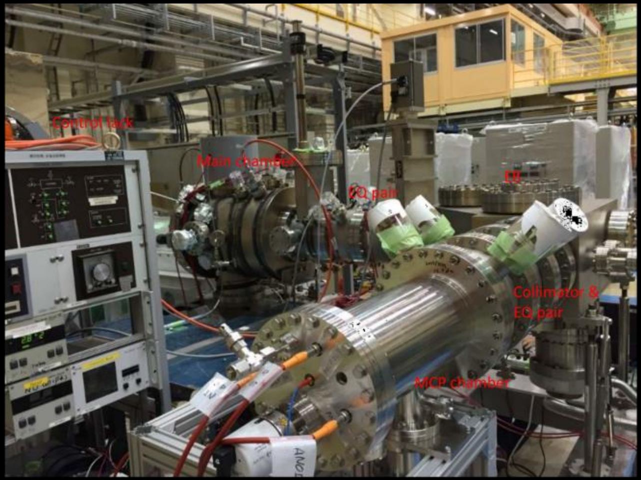
Challenge Muon Acceleration

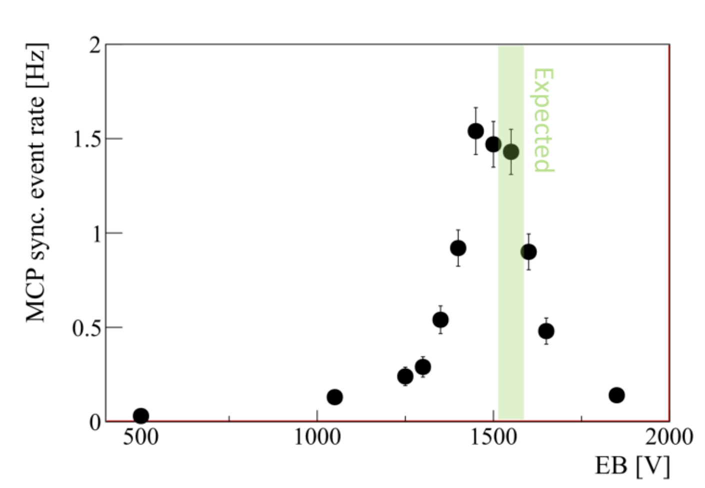
Y. Kondo, M. Otani, R. Kitamura, RIKEN, KEK

- RFQ was successfully operated @ J-PARC LINAC build.



- E-static elements were assembled and operated well @ J-PARC MLF



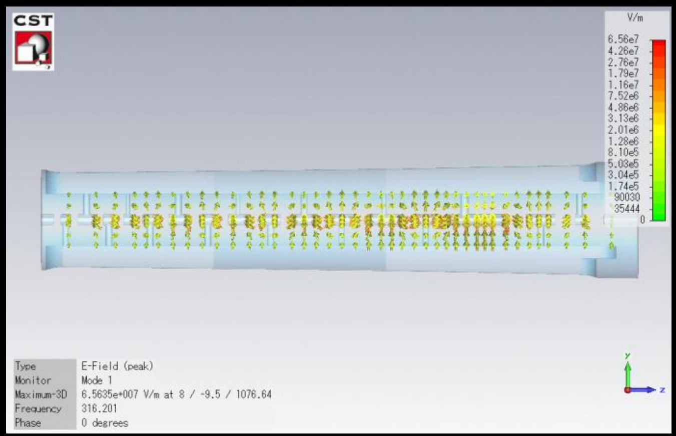


Equipments for the RFQ acceleration are ready

IH LINAC for Low β (0.08 ~ 0.27)

- Alternate Phase Focusing (APF) is employed for efficient acc.
- Design with computer calculation is being progress.

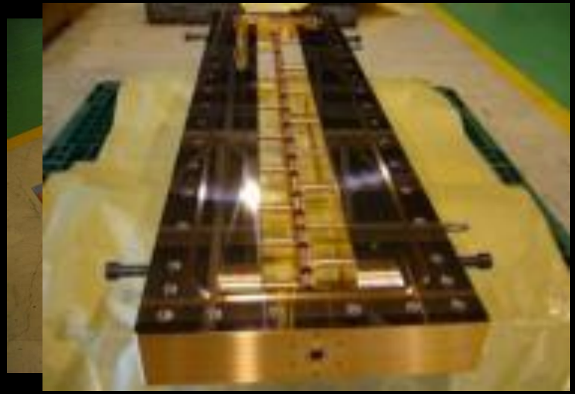
Calculation with CST

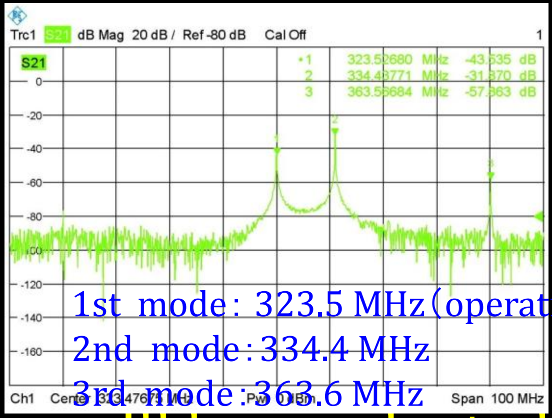


Parameters for preproduction

Operation parameters (IH-DTL ver.153)	
Frequency [MHz]	324
Length of IH-DTL [mm]	1440
Number of Gaps [gaps]	17
Electric field on the axis [MV/m]	9.00
Average bohr radius [mm]	7.5
peak Power [kW]	336.11
Q value	11822.00
Shunt impedance [MΩ /m]	56.57
Input energy [keV]	340.00
Output energy [MeV]	3.75
Acceptance [π mm-mrad]	1.8

- Preproduction prototype was fabricated.





1st mode: 323.5 MHz (operating mode)
2nd mode: 334.4 MHz
3rd mode: 363.6 MHz

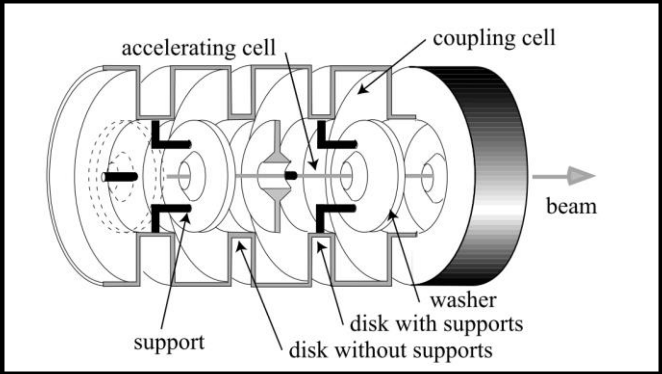
Prototype test and further design will be conducted

M. Otani,
Y. Iwashita

DAW for middle β (0.27 ~ 0.7)

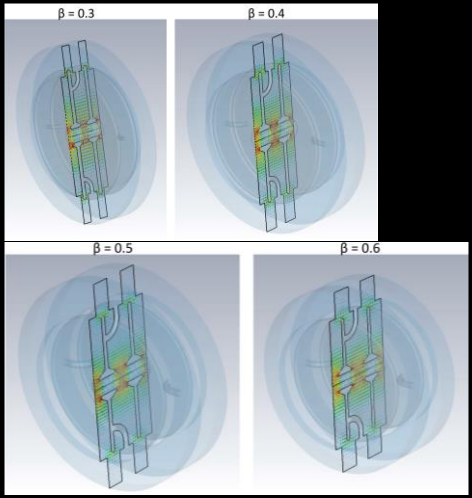
- DAW (Disk And Washer)
  - One of the coupled cell LINAC
  - Needs fa = fc
  - Higher efficiency is favored

Bi-periodic L-support DAW

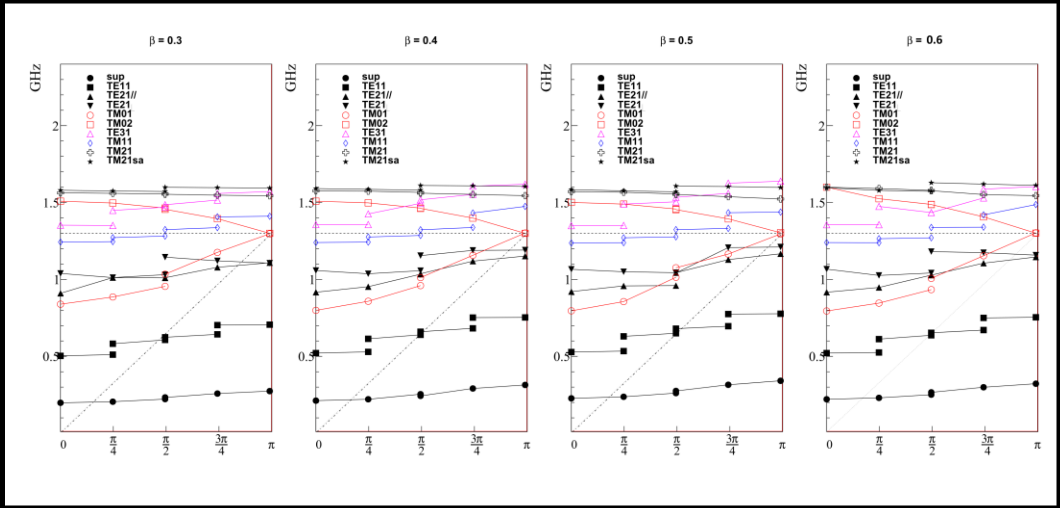


- Optimization of the cell design was done with CST MW studio

Calculation with CST MW



Dispersion curves



Cell design was finished and proto-type will be fabricated.

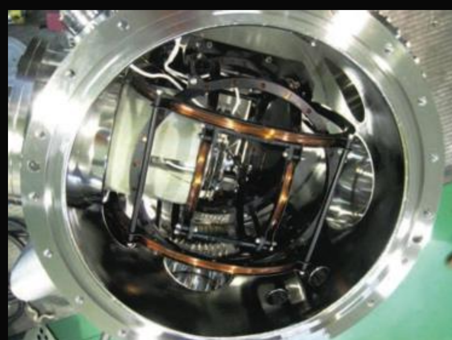
Details will be presented in poster session today.

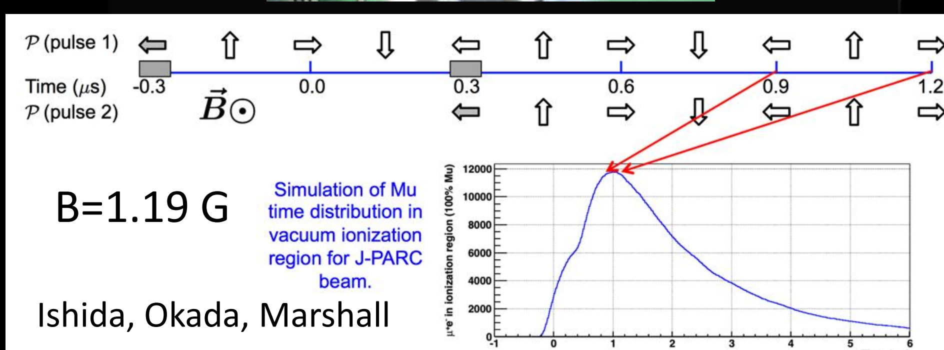
Spin reversal

- Powerful method to understand our systematics.
- Two apparatus are being developed.

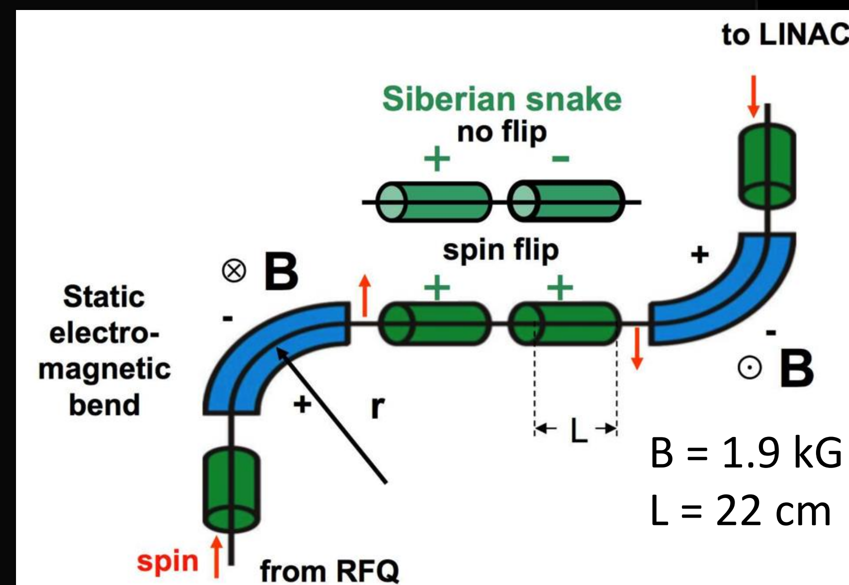
$$
\begin{aligned}
R(t, E_e) &= \frac{N^+(t, E_e) - N^-(t, E_e)}{N^+(t, E) + N^-(t, E_e)} \\
&= \cos(\omega_a t + \phi)
\end{aligned}
$$

At rest (Muonium)





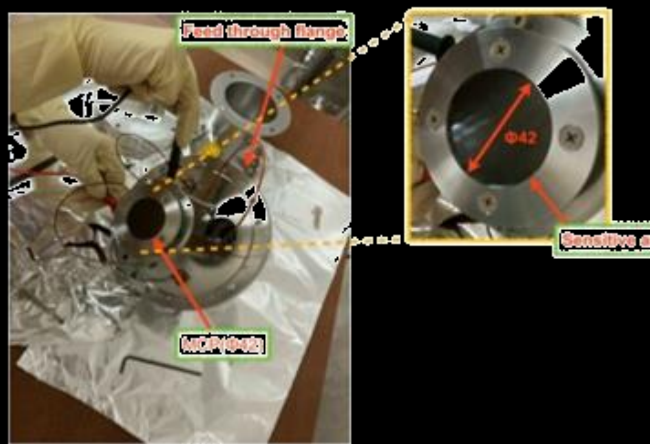
In flight



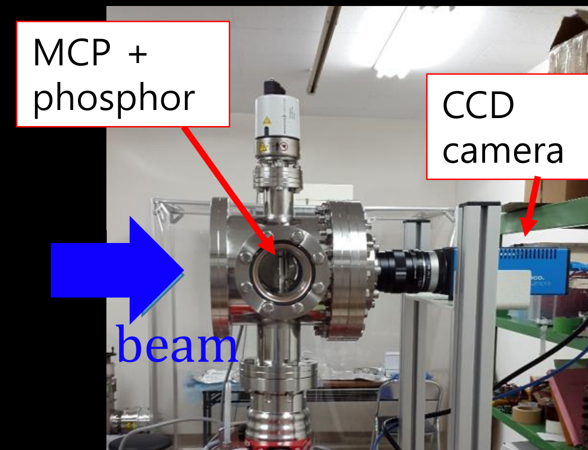
Beam Monitors

- MCP based detectors are being developed.

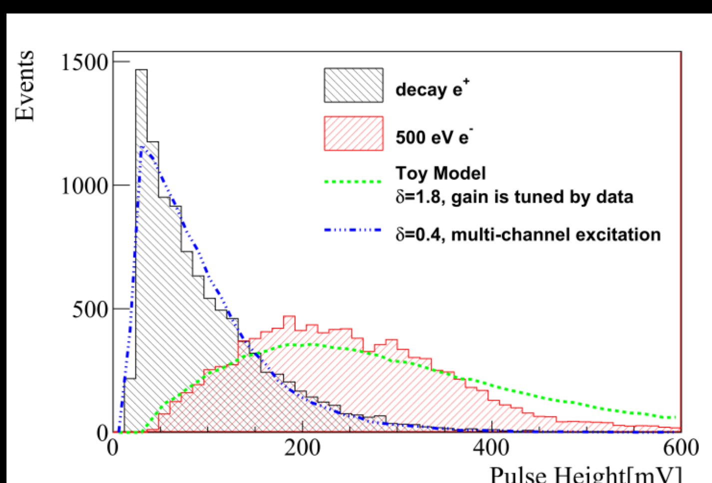
MCP installation



Profile monitor



- MCP performances were investigated with radiation source and decay-e^+

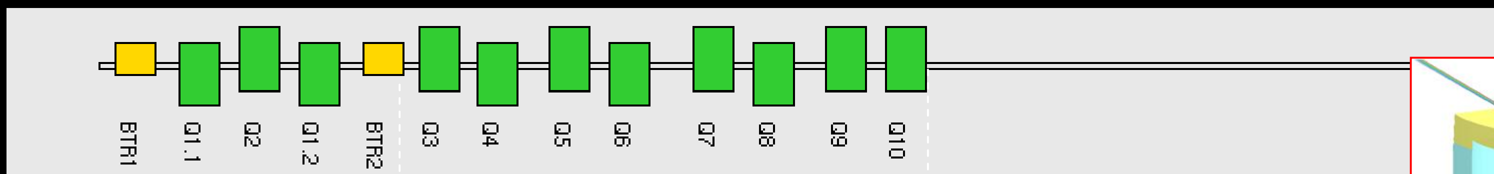


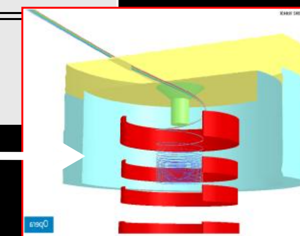
- MCP has enough efficiency for slow muon
- Profile monitor will be tested by muon beam

Injection, Kick and Weak Focusing

H. Iinuma, H. Nakayama, KEK

- Injection beamline was designed by simulation





Bend beam and control dispersion zero

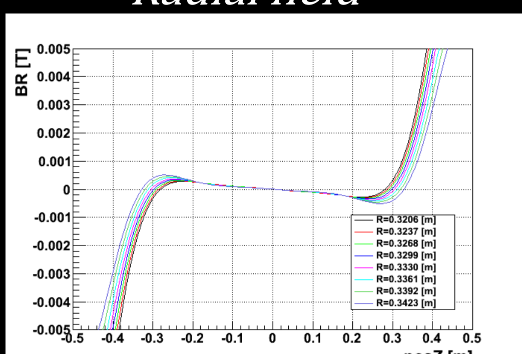
Apply X-Y coupling

Free drift LD=350cm

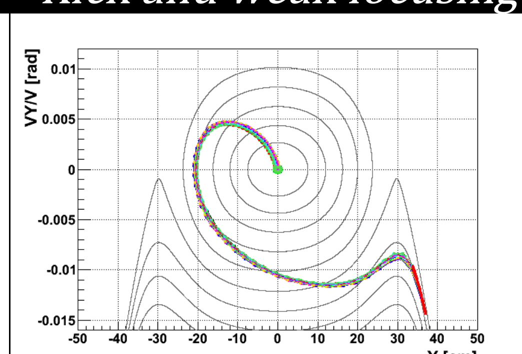
- Kicker and weak focusing will be tested by electron based on the simulation study.

Simulation study

Radial field

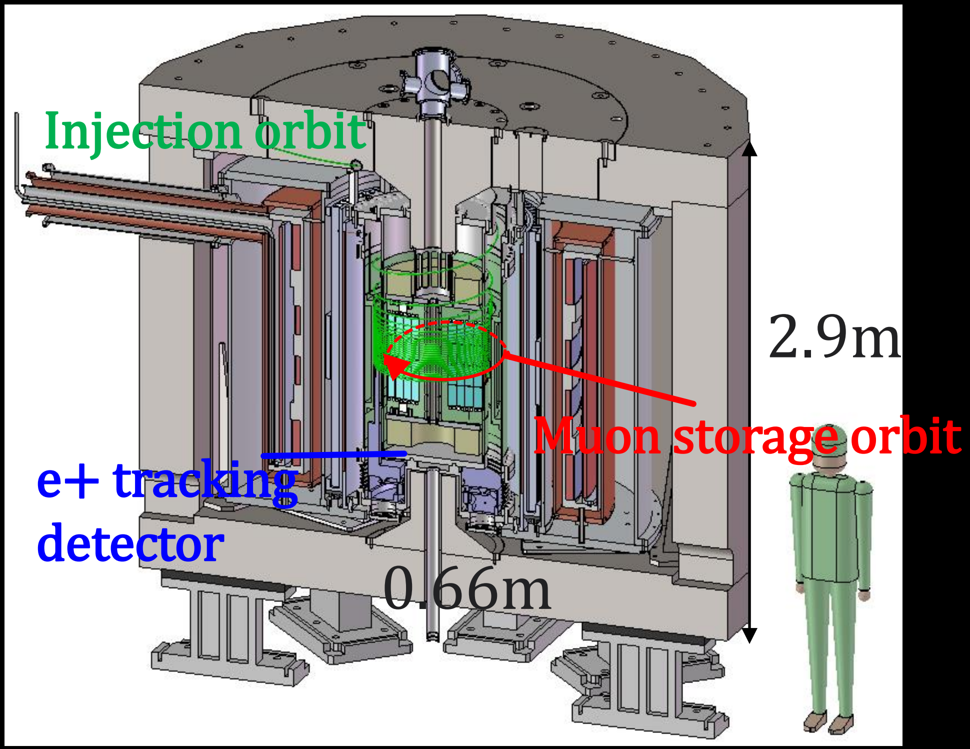


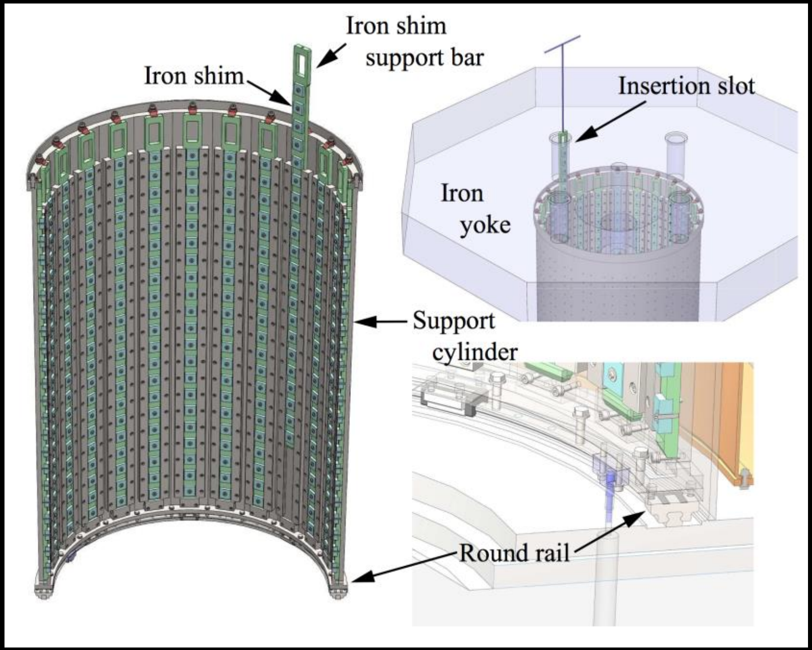
Kick and weak focusing



Test with electron

Storage magnet



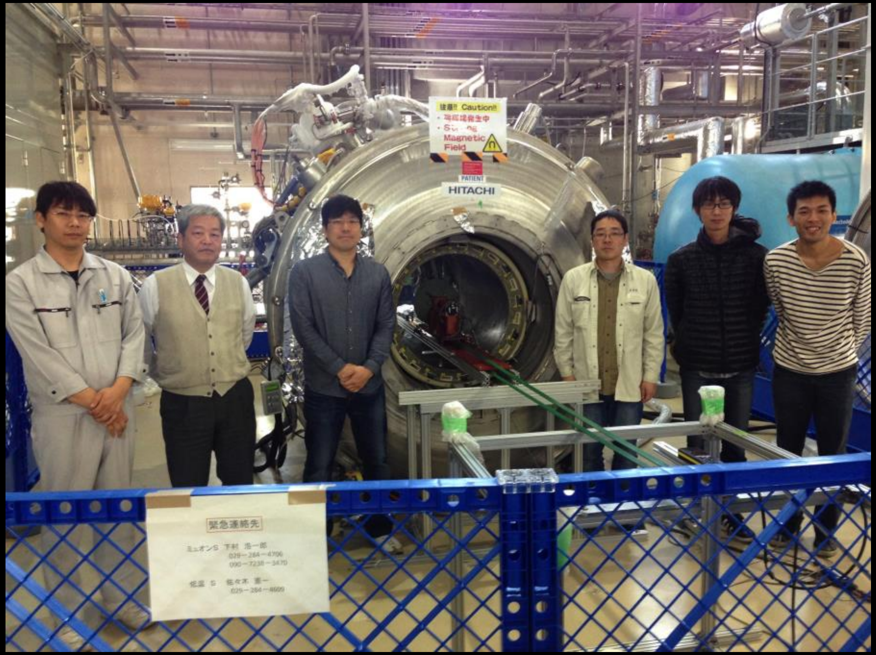


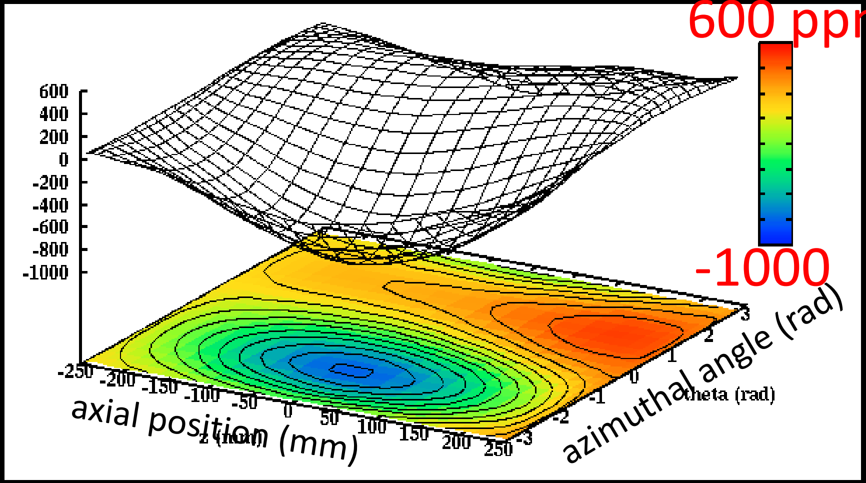
- 4 super-conducting coils supply injection field (Br), focusing field and main field.
  - Main field: 3T with local uniformity of 1ppm by iron shimming.

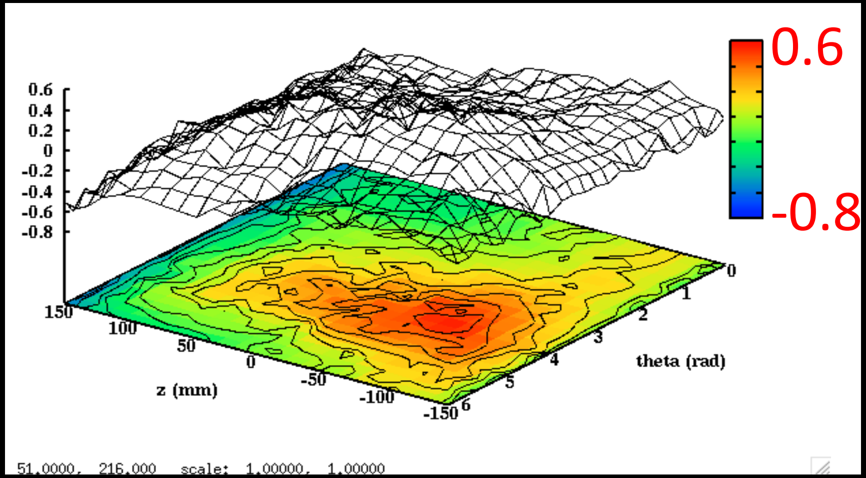
B Field Control

K. Sakaki,
MuSEUM collab. etc

Shimming test with the MuSEUM magnet (1.7T)



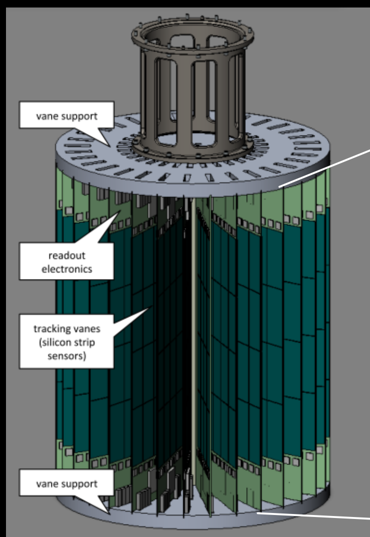


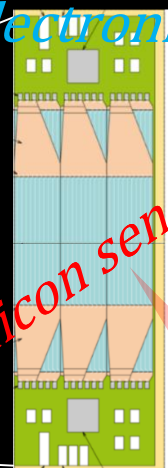


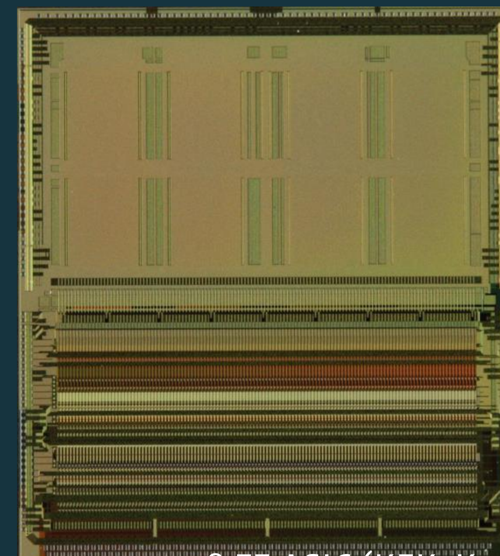
ppm level uniformity is achieved → Shimming method is established

Detector

- Highly segmented silicon strip tracker



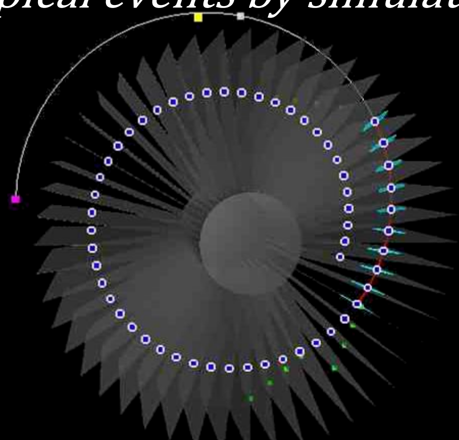




128 FE ASIC (KEK, Kyushu)

Test Si-strip sensor (KEK, Kyushu)

Typical events by simulation

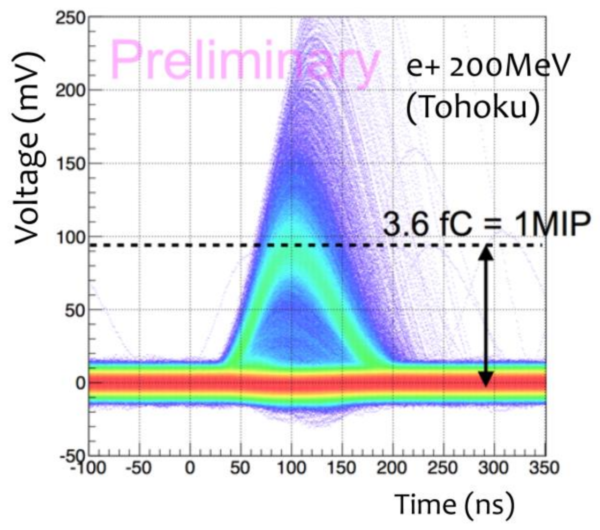


Performance

- Proto-type was fabricated and tested by beam tests.
  - DC positron beam @Tohoku
    - Evaluation of the performances to actual particle
  - Positrons from pulsed μ@J-PARC
    - Evaluation of the performance at actual experimental site

@Tohoku, 2014 Sep.

@J-PARC, 2014 Jun.



Move to production phase now (BUDGET~1M $ was approved.)

Collaboration Status

- Technical Design Report was submitted
  - We succeeded to develop efficient Mu target and can achieve 0.37 ppm for g-2 and 1.3 x 10^{-21} e・cm for EDM, respectively.
  - Data taking from 2019 is technically possible.

Table 13.1: *Efficiency and beam intensity*

Quantity	Reference	Efficiency	Cumulative	Intensity (Hz)
Muon intensity at production target	[2]			1.99E+09
H-line transmission	[2]	1.62E-01	1.62E-01	3.22E+08
Mu emission	[3]	3.82E-03	6.17E-04	1.23E+06
Laser ionization	[4]	7.30E-01	4.50E-04	8.97E+05
Metal mesh	[5]	7.76E-01	3.49E-04	6.96E+05
Init.Acc.trans.+decay	[5]	7.18E-01	2.51E-04	5.00E+05
RFQ transmission	[6]	9.45E-01	2.37E-04	4.72E+05
RFQ decay	[6]	8.13E-01	1.93E-04	3.84E+05
IH transmission	design goal	1.00E+00	1.93E-04	3.84E+05
IH decay	[7]	9.84E-01	1.90E-04	3.78E+05
DAW transmission	design goal	1.00E+00	1.90E-04	3.78E+05
DAW decay	[8]	9.94E-01	1.88E-04	3.76E+05
High beta transmission	design goal	9.80E-01	1.85E-04	3.68E+05
High beta decay	[9]	9.88E-01	1.83E-04	3.64E+05
Injection transmission	design goal	1.00E+00	1.83E-04	3.64E+05
Injection decay	[10]	9.90E-01	1.81E-04	3.60E+05
Detector start time	[10]	9.27E-01	1.67E-04	3.34E+05
Muon at storage				3.34E+05

Technical Design Report
for
the Measurement of the Muon Anomalous Magnetic Moment $g-2$ and Electric Dipole Moment at J-PARC

May 15, 2015

Summary

- J-PARC E34 proves and search for the muon g-2 anomaly and EDM, respectively, with different way to BNL/Fermi g-2
- Recent major R&D achievements are reported here:
  - Surface muon beamline was designed and will be constructed next year.
  - ~10 times efficient Mu production target.
  - Lyman-α @ J-PARC U-line
  - Ultra-cold muon production @ RIKEN-RAL
  - RFQ & E-static elements are ready for muon acceleration
  - IH cavity proto-type
  - DAW cell design and proto-type cell in near future
  - Demonstration of injection & kick & weak focusing by electron
  - Establish iron shimming for ppm uniformity of B-field
  - Proto-type detector was evaluated with beam
    Real detector will be launched soon
  - …
- We submitted TDR and aim to start physics data taking in 2019.

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BACKUP